CLAIMS

What is claimed is:

1. A method for generating electromagnetic radiation comprising: producing free electrons; selecting from said free electrons a group of electrons having a reduced energy spread; and undulating the group of free electrons with an undulator in an undulation zone, said undulator having an intensity sufficient to cause the emission of radiation from the group of electrons and causing the electron radiation to interact with radiation from the undulator to bunch the group of electrons, whereby such bunching generates further emission of radiation.

2. A method of Claim 1, wherein said producing of free electrons includes accelerating free electrons by means of an electron beam in a plasma.

3. A method of Claim 1, wherein said producing of free electrons includes accelerating free electrons in a plasma.

4. A method of Claim 1, wherein said producing of free electrons includes accelerating free electrons by means of a laser in a plasma.

5. A method of Claim 4, wherein the accelerating is accomplished at least in part by a plasma wakefield.

6. A method of Claim 5, wherein the accelerating is assisted by a direct-current (DC) electric field.

7. A method of Claim 1, wherein before said undulating, a beam of at least one pulse of electromagnetic radiation is produced; and wherein said free electrons and pulse of electromagnetic radiation coincide during said undulating to further enhance emission of radiation.

8. A method of Claim 7, wherein said undulating constitutes a first stage of undulating for said group of free electrons that is a first group of free electrons; a second group of free electrons is produced; and radiation from said first stage of undulating is added to a second stage of undulating comprising the undulating of the second group of free electrons.

9. A method of Claim 1, wherein said undulating is accomplished by an electromagnetic laser wiggler.

10. A method of Claim 1, wherein said undulating is accomplished by a magnetostatic undulator.

11. A method of Claim 1, wherein said selecting is accomplished by magnetic filtering.

12. A method of Claim 11, wherein said magnetic filtering is accompanied by refocusing of the electron beam to the undulation zone.

13. A method of Claim 1, wherein said selecting is accomplished by preferentially accelerating those electrons having a narrow energy range in said group of electrons.

14. A method of Claim 13, wherein said preferential acceleration is accomplished by means of optical injection, comprising generating a plasma and introducing additional laser pulses in the plasma.

15. A method of Claim 14, wherein said preferential acceleration is accomplished by means of a sharp density discontinuity within the plasma.

16. A method of Claim 13, wherein said preferential acceleration is accomplished by means of multistage acceleration, comprising further accelerating said first group of accelerated electrons.

17. A method to lithographically pattern a substrate comprising generating electromagnetic radiation by the method of Claim 1 and directing said radiation to the substrate.

18. A method to lithographically pattern a substrate comprising generating electromagnetic radiation by the method of Claim 1 and directing said radiation to a mask and then to the substrate.

19. A method for producing data for analysis of a fine structure comprising generating electromagnetic radiation by the method of Claim 1 and directing said radiation to the structure.

20. A method for producing data for analysis of a fine structure comprising generating electromagnetic radiation by the method of Claim 1 and directing said radiation to the structure and then imaging said radiation to a detector.

21. A method to produce data for analysis of a protein structure comprising generating electromagnetic radiation by the method of Claim 1 and directing said radiation to the protein structure.

22. A method to produce data for analysis of a protein structure comprising generating electromagnetic radiation by the method of Claim 1 and directing said radiation to the protein structure and then to a detector.

23. The method of Claim 1, wherein said selecting is accomplished by preferentially accelerating those electrons of said group having a narrow energy range.

24. The method of Claim 23, wherein said preferentially accelerating is accomplished by multi-stage acceleration.

25. The method of Claim 1, wherein said emission of radiation is at a fundamental frequency.

26. The method of Claim 1, wherein said emission of radiation comprises multiple frequencies that are multiples of a fundamental frequency.

27. The method of Claim 26, wherein said multiple frequencies are generated by said undulator characterized by a field strength that is essentially non-sinusoidal.

28. A method for generating electromagnetic radiation comprising: producing a group of free electrons, undulating the group of free electrons and causing emission of radiation.

29. A method of Claim 28, wherein said producing includes accelerating free electrons by means of an electron beam in a plasma.

30. A method of Claim 28, wherein said producing of free electrons includes accelerating free electrons in a plasma.

31. A method of Claim 28, wherein said producing of free electrons includes accelerating free electrons by means of a laser in a plasma.

32. A method of Claim 31, wherein the accelerating is accomplished at least in part by a plasma wakefield.

33. A method of Claim 32, wherein the accelerating is assisted by a direct-current (DC) electric field.

34. The method of Claim 28, wherein said group of free electrons is mono-energetic.

35. A method of Claim 28, wherein said undulating is accomplished by an electromagnetic laser wiggler.

36. A method of Claim 28, wherein said undulating is accomplished by a magnetostatic undulator.

37. A method to lithographically pattern a substrate comprising generating electromagnetic radiation by the method of Claim 28 and directing said radiation to the substrate.

38. A method to lithographically pattern a substrate comprising generating electromagnetic radiation by the method of Claim 28 and directing said radiation to a mask and then to the substrate.

39. A method for producing data for analysis of fine structure comprising generating electromagnetic radiation by the method of Claim 28 and directing said radiation to the structure.

40. A method for producing data for analysis of fine structure comprising generating electromagnetic radiation by the method of Claim 28 and directing said radiation to the structure and then imaging said radiation to a detector.

41. A method to produce data for analysis of a protein structure comprising generating electromagnetic radiation by the method of Claim 28 and directing said radiation to the protein structure.

42. A method to produce data for analysis of a protein structure comprising generating electromagnetic radiation by the method of Claim 28 and directing said radiation to the protein structure and then to a detector.

43. The method of Claim 28, wherein said emission of radiation is at a fundamental frequency.

44. The method of Claim 28, wherein said emission of radiation comprises multiple frequencies that are multiples of a fundamental frequency.

45. The method of Claim 44, wherein said multiple frequencies are generated by said undulator characterized by a field strength that is essentially non-sinusoidal.

46. A method for generating electromagnetic radiation comprising: generating a first group of free electrons and separately generating seed radiation; undulating the first group of free electrons in the presence of the seed radiation, thereby producing first amplified radiation; generating a second group of free electrons; and undulating the second group of free electrons and the first amplified radiation in a second undulator to produce second amplified radiation.

47. A method for generating electromagnetic radiation comprising:

(a) generating a group of free electrons and separately generating seed radiation; undulating the group of free electrons in the presence of the seed radiation, thereby producing upstream amplified radiation; and

(b) generating a further group of free electrons, and undulating the further group of free electrons and the upstream amplified radiation in a downstream undulator to produce a downstream amplified radiation.

48. The method of Claim 47, wherein Step (b) is repeated for a multi-staged amplification of three stages or more.

49. A method for generating electromagnetic radiation comprising: producing a first group of free electrons; undulating a second group of free electrons from among said first group of free electrons, said second group of free electrons having a reduced energy spread as compared to said first group; where said undulator has an intensity sufficient to cause the emission of radiation from the second group of electrons and causes the electron radiation to interact with radiation from the undulator.

50. An apparatus for generating radiation comprising a source of an energetic beam of free electrons and an undulator adapted to cause said free electrons to undergo undulation to produce electromagnetic radiation.

51. The apparatus of Claim 50, wherein said source of energetic free electrons comprises a cathode target comprised of an ionized gas or an ionized clustered gas.

52. The apparatus of Claim 51, which comprises a source of said ionized gas or ionized clustered gas being a source selected from the group consisting of gas jet, filed capillary or backfilled chamber, and combinations thereof.

53. The apparatus of Claim 51, wherein said source of energetic free electrons comprises a cathode target comprised of an ionized solid.

54. The apparatus of Claim 53, which comprises a source of said ionized solid being a source selected from the group consisting of moving wire spool, rotating disk, liquid jet, liquid droplets, and combinations thereof.

55. The apparatus of Claim 50, wherein said undulator comprises a series of magnets arranged to provide a field perpendicular to the direction of propagation of said electron beam and to alternate in a field direction along the direction of propagation of said electron beam.

56. The apparatus of Claim 55, which includes permanent magnets arranged to provide said field normal to the direction of propagation.

57. The apparatus of Claim 55, which includes variable electromagnets providing said field normal to the direction of propagation.

58. The apparatus of Claim 50, which comprises a source of photons arranged to direct and focus said photons to coincide with said beam of free electrons in said undulator.

59. The apparatus of Claim 50, which further comprises a filter between said free electron source and undulator for filtering the free electrons thereby providing a group of electrons having a reduced energy spread.

60. The apparatus of Claim 59, wherein said filter comprises one or more magnets.

61. The apparatus of Claim 50, wherein said source of free electrons comprises an accelerator for accelerating certain free electrons to produce a group of select electrons having a reduced energy spread.

62. A method to generate electromagnetic radiation comprising: producing free electrons; arranging said free electrons into groups of free electrons having corresponding different energy ranges and spatially separating said groups; and undulating the groups of free electrons essentially simultaneously with respective undulators, said undulators each having an

intensity sufficient to cause the emission of radiation from a respective one of said groups of free electrons and causing the electron radiation to interact with radiation from the undulator to bunch the electrons of a respective said group, whereby such bunching generates further emission of radiation of differing wavelengths corresponding to said groups respectively.

63. A method of generating electromagnetic radiation comprising: producing free electrons arranged in spatially separate groups of free electrons having essentially non-overlapping energy ranges; and undulating the spatially separate groups of free electrons essentially simultaneously, causing emission of radiation at various wavelengths.

64. The method of Claim 1, wherein said producing of free electrons comprises photo-ionization of one or more selected from the group consisting of gas, liquid and solid.

65. The method of Claim 2, wherein said plasma is produced by photo-ionization of one or more selected from the group consisting of gas, liquid and solid.

66. The method of Claim 8, wherein said radiation from said first stage of undulating is collected and focused with x-ray optics before being added to said second stage of undulating.

67. The method of Claim 66, wherein said focusing is by at least one selected from the group consisting of curved mirrors, zone plates and capillary fibers.

68. An apparatus for generating electromagnetic radiation comprising:

(a) a source of a group of free electrons;

(b) a source of seed radiation;

(c) an undulator for undulating the group of free electrons in the presence of the seed radiation, thereby producing upstream amplified radiation;

(d) a source of a further group of free electrons; and

(e) a downstream undulator for undulating the further group of free electrons and the upstream amplified radiation to produce a downstream amplified radiation.

69. The apparatus of Claim 68, having one or more additional downstream undulators for a multi-staged amplification of three stages or more.

70. The apparatus of Claim 68 that comprises a collector for collecting said upstream radiation and x-ray optics for focusing said upstream radiation, said collector and x-ray optics arranged to direct said upstream radiation to said downstream undulator.